

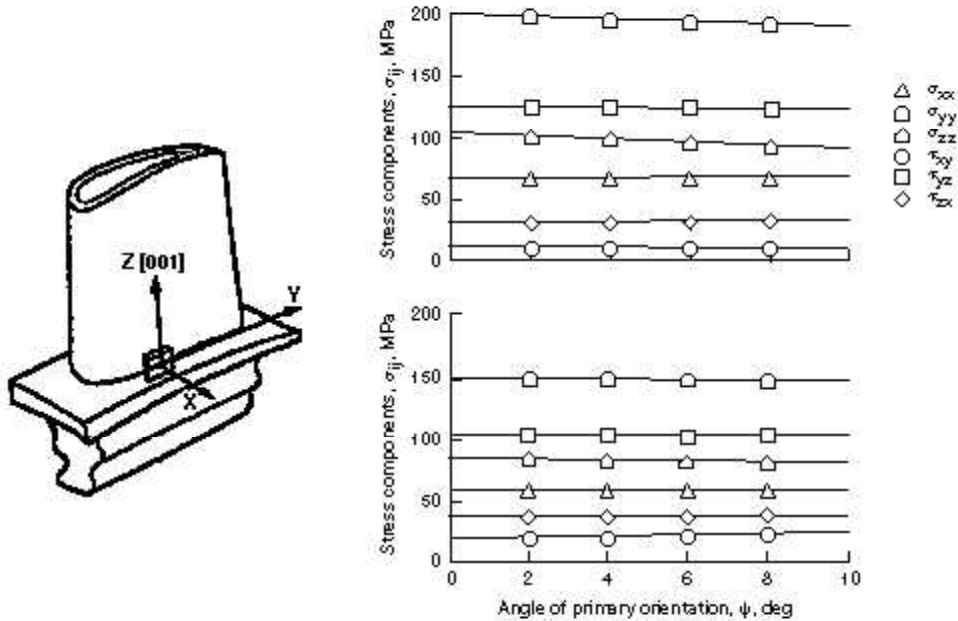
# **Thermal and Structural Analysis Conducted on Hollow-Core Turbine Blade of the Space Shuttle Main Engine**

Hot-section components of spacecraft engines are exposed to severe thermal-structural loading conditions, especially during the startup and shutdown portions of the engine cycle. For instance, the thermal transient during startup within the space shuttle main engine (SSME) can lead to a gas temperatures in excess of 3000 °C, affecting the operating life of key components, such as the turbine blades.

To improve the durability of these components and in particular the turbine blade, single-crystal superalloys have been considered. PWA-1480, a nickel-base superalloy, has been used as the turbine blade material for the Alternate Turbopump Development (ATD) program for the SSME.

Turbine blades made out of single-crystal superalloys, including PWA-1480, are directionally solidified along the low-modulus [001] crystallographic direction. The directional solidification process usually generates a secondary crystallographic direction, [010], that is randomly oriented with respect to fixed geometric axes in the turbine blade. Moreover, because of the anisotropic nature of the single crystal, the stress-strain response and the dynamic characteristics of any component made out of single crystal (such as the turbine blade) would depend on both the secondary and the primary orientation angles. This work addresses the influence of primary and secondary orientations on the elastic response of an SSME hollow-core, [001]-oriented nickel-base single-crystal superalloy (PWA 1480) turbine blade, under combined thermal and mechanical loading conditions. A previous study (ref. 1) involving a flat plate of single-crystal material subjected to thermal loading showed that the influence of the secondary orientation on the elastic stress response is very substantial. Highest stresses occurred at a secondary orientation of 45°, which identified it as the most critical secondary orientation. Also, when the primary orientation angle was constrained between 0° and 10°, its influence on the elastic stresses generated within the turbine blade was much lower than the influence of the secondary orientation angle, which is not usually controlled.

This study consisted of thermal-structural analysis of an SSME-type turbine blade subjected to thermal and mechanical loads characteristic of engine use. The objective was to assess the influence of both the primary and secondary crystallographic orientation on the stresses developed and to compare the results with the conclusions obtained from earlier analyses of simpler structures (ref. 2). The figures show the results, demonstrating that secondary crystallographic orientation has a strong influence on the stresses in the turbine blade, an observation consistent with earlier findings on much simpler structures.



Left: Schematic of an SSME hollow-core turbine blade. Right: Influence of primary and secondary orientation angles under combined thermal and mechanical loading.

## References

1. Kalluri, S.; Abdul-Aziz, A.; and McGaw, M.: Elastic Response of [001]-Oriented PWA 1480 Single Crystal--The Influence of Secondary Orientation. SAE Transactions, vol. 100, SAE Paper 91-1111, 1991.
2. Abdul-Aziz, A.; Kalluri, S.; and McGaw, M.A.: The Influence of Primary Orientation on the Elastic Response of a Nickel-Base Single-Crystal Superalloy. ASME Paper 93-GT-376, 1993.